COPY

(2)

US Army Corps of Engineers

AD-A200 040

ENVIRONMENTAL IMPACT RESEARCH PROGRAM

TECHNICAL REPORT EL-88-13

TECHNIQUES TO INCREASE EFFICIENCY AND REDUCE EFFORT IN APPLICATIONS OF THE HABITAT EVALUATION PROCEDURES (HEP)

by

James S. Wakeley, L. Jean O'Neil

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39181-0631

September 1988

Final Report

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under EIRP Work Unit 32390

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

AD-A200 340

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188
Exp Date Jun 30, 1986

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report EL-88-13	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION USAEWES Environmental Laboratory 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) PO Box 631 Vicksburg, MS 39181-0631	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION US Army Corps of Engineers 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20314-1000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO EIRP 32390

11. TITLE (Include Security Classification)
Techniques To Increase Efficiency and Reduce Effort in Applications of the Habitat Evaluation Procedures (HEP)

12. PERSONAL AUTHOR(S)
Wakeley, James S.; O'Neil, L. Jean

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Final report	FROM ____ TO ____	September 1988	60

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Environmental impact assessment, ~~HEP~~ Study design
Habitat evaluation, ~~HSI models~~ Wildlife habitat. (JES)
~~Planning~~

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The US Fish and Wildlife Service's Habitat Evaluation Procedures (HEP) are widely used to assess the impacts of major water resource projects. These procedures provide a flexible tool that is also valuable when study objectives are limited or when lower resolution is desired. This report describes various options that can be used to tailor HEP to a particular application and level of effort desired by the user. Several techniques improve efficiency without sacrificing reliability; others reduce the resolution of the analysis, and their use depends upon the objectives of the study.

The amount of effort involved in a habitat evaluation can be reduced by (a) using only those portions of the HEP process that are appropriate to the application and (b) simplifying the process, particularly those steps that affect the intensity of sampling. Kaywr

(Continued)

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL	22b TELEPHONE (Include Area Code) / 22c OFFICE SYMBOL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. ABSTRACT (Continued).

Options discussed in this report include focusing on important cover types, choosing evaluation species that have simple models, using community models, modifying models to eliminate variables or reduce resolution, tailoring sampling effort to the shape of suitability index curves, and using portable data collectors.

PREFACE

This study was sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Environmental Impact Research Program (EIRP), Work Unit 32390, Application of Habitat-Based Evaluation Methods. Technical Monitors were Dr. John Bushman and Mr. David P. Buelow, HQUSACE, and Mr. Dave Mathis, Dredging Division, HQUSACE. The report was prepared by Dr. James S. Wakeley and Ms. L. Jean O'Neil of the Wetlands and Terrestrial Habitat Group (WTHG), US Army Engineer Waterways Experiment Station (WES). During the study, Mr. Chester O. Martin was Team Leader, Wildlife Resources Team; Dr. Hanley K. Smith was Chief, WTHG; Dr. Conrad J. Kirby was Chief, Environmental Resources Division (ERD); and Dr. John Harrison was Chief, Environmental Laboratory. Dr. Roger T. Saucier, WES, was Program Manager of EIRP.

Technical reviews were provided by Mr. Raymond C. Solomon, US Fish and Wildlife Service, Fort Collins, CO; Dr. Andrew C. Miller, Aquatic Habitat Group, ERD; Mr. David A. Nelson, Coastal Ecology Group, ERD; Dr. Thomas H. Roberts, WTHG, ERD; Dr. Michael F. Passmore, US Army Engineer (USAE) District, Walla Walla; Dr. Thomas M. Pullen, USAE Division, Lower Mississippi Valley; Mr. Terry Siemsen, USAE District, Louisville; and Mr. Phillip J. Pierce, USACE. The report was edited by Ms. Lee T. Byrne of the WES Information Technology Laboratory.

Cover photograph of pumpkinseed fish is used courtesy of Carolina Biological Supply Company.

COL Dwayne G. Lee, EN, was the Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

This report should be cited as follows:

Wakeley, James S., and O'Neil, L. Jean. 1988. "Techniques To Increase Efficiency and Reduce Effort in Applications of the Habitat Evaluation Procedures (HEP)," Technical Report EL-88-13, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	0.4046	hectares
inches	2.5400	centimeters
pounds (mass)	0.4536	kilograms
square feet	0.0929	square meters

TECHNIQUES TO INCREASE EFFICIENCY AND REDUCE EFFORT IN APPLICATIONS OF THE HABITAT EVALUATION PROCEDURES (HEP)

PART I: INTRODUCTION

Background

1. The Habitat Evaluation Procedures (HEP) (US Fish and Wildlife Service (USFWS) 1980, 1981) were developed in response to a need for an objective, reliable, and well-documented method to assess the impacts of major water resource projects. Since its inception, HEP has been regarded by many potential users as a complex and rigid procedure that is applicable only to large-scale projects involving alternative project designs, multiple target years, and several potential mitigation plans. In fact, HEP is a flexible tool that can be tailored to a particular application and to the level of effort desired by the user.

2. There are two general approaches to reducing effort in a HEP analysis. One is to use only those portions of HEP (defined broadly as including the use of habitat suitability models) that are appropriate to the objectives of the study, while maintaining the typical level of precision and reliability of results. This approach may be appropriate when objectives are limited and do not require the complete HEP process. Examples include habitat inventories and monitoring programs, management plans for refuges and recreation areas, and impact assessments that do not involve mitigation plans.

3. The second approach is to simplify the procedure to achieve an outcome that may be less reliable than a typical HEP but is still sufficient to meet the objectives of the study or the level of decision making. Low-resolution habitat analyses may be appropriate (a) where study areas are either very large or very small; (b) there are limited personnel, time, and funds; (c) anticipated impacts are minimal; or (d) the resources involved are ubiquitous or of low priority. For this report, "low resolution" is defined as producing a result that may be less reliable than that obtained with a typical HEP analysis as described in USFWS (1980). Reliability may be diminished due to reduced accuracy or precision of estimates or because potentially useful information was not gathered.

4. The purpose of this report is to identify steps in the HEP process where the expenditure of time and effort can be reduced. Because much of the effort in a HEP study is devoted to sampling habitat variables, the emphasis here will be on the selection, modification, and application of habitat suitability models to improve sampling efficiency. Many users of HEP already employ some of the options presented here. For them, this report can serve as a guide for further increases in efficiency.

Overview of HEP

5. HEP is an accounting system for quantifying and displaying habitat availability for fish and wildlife. HEP is based on Habitat Suitability Index (HSI) models that quantitatively describe the habitat requirements of a species or group of species. HSI models use measurements of appropriate variables to rate the habitat on a scale of 0 (unsuitable) to 1.0 (optimal). In a typical HEP study, a number of evaluation species* are chosen for each cover type in the study area. Species may be chosen because of their ecological, recreational, or economic value; because they represent groups of species (i.e., guilds) having similar habitat needs; or because they represent important habitats in the study area. Advice on selecting evaluation species is given by Roberts and O'Neil (1985a,b).

6. After cover types in the study area have been mapped and evaluation species selected, habitat variables contained in the species models are measured from maps, aerial photographs, or by onsite sampling. HSI values are then calculated, and the number of habitat units (HUs) is determined for each evaluation species. One HU is equivalent to 1 acre** of optimal habitat; therefore, the number of HUs for a species is calculated as the number of acres of available habitat times its suitability (HU = HSI × area). For species that use more than one cover type, an aggregate HSI is determined for the cover types used and multiplied by area to obtain HUs.

---

* HEP was developed primarily as a species-oriented assessment method but is equally applicable to studies involving other kinds of evaluation elements. Appropriate elements might include a species life stage (e.g., larval fish), life requisite (e.g., brood cover), guild (e.g., bottom-feeding fishes), or plant or animal community (e.g., riparian forest).

** A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

7. HUs available for each evaluation species are estimated for each of several target years (TYs) over the life of the project; estimates of future habitat conditions are made for both "with-project" and "without-project" alternatives. Project impacts are then estimated by calculating the difference in average annual habitat units (AAHUs) for each species. Depending upon the size of the project, impacts may be estimated for various alternative project designs, with or without management plans to compensate for losses in habitat value. Development of mitigation plans involving trade-offs of one sort of habitat for another may involve the use of relative value indices (RVIs) that express the relative importance or priority of the evaluation species or their habitats.

PART II: REDUCING EFFORT IN A HEP STUDY

8. The first step in tailoring HEP to a particular application is for the various agencies and other interested parties to specify priorities for cover types and evaluation elements, establish objectives, and determine the level of resolution required for the study. The next step is to identify and use only those portions of the procedure that are appropriate to the project. HEP has the potential to generate information beyond the needs of many projects. The objectives of a management-oriented study, for example, might be satisfied by determining HSI values for selected species without using the HEP accounting system at all. An estimate of available HUs may be all that is required for a general habitat inventory, and a simple impact analysis does not necessarily involve RVIs, management plans, or compensation needs. Table 1 lists some typical applications and indicates which components of HEP may be most useful.

Table 1

Components of HEP and Their Use in Various Applications

	Components of HEP					
Application	Cover Types	Habitat Quality Models	Baseline Habitat Units	Future Habitat Units	Project Alter-natives	Trade-offs
Information gathering						
Habitat inventory	X*	X	X			
Monitoring	X	X	X	-		
Land-use planning						
Site selection	X	X	X	-		-
Establishment of natural areas	X	X	X	-		
Project planning	X	X	X	X	X	X
Fish and wildlife management	X	X	-	-	-	-
Impact assessment						
Permit actions	X	X	X	-	-	-
Damage assessment	X	X	X	-	-	-
Cumulative impacts	X	X	X	X	-	-
Mitigation planning	X	X	X	X	-	X

* Required components are indicated with an "X", optional components with a "-".

9. Additional options for adjusting the level of effort in a HEP analysis are presented below. These options are organized into sections concerning cover types, evaluation elements, models, sampling, and data handling and analysis. The reader should be aware that many of the following suggestions result in reduced resolution and reliability of the habitat analysis, and therefore may not be appropriate for some applications. Table 2 is designed to help in the selection of appropriate alternatives for high- and low-resolution studies.

Cover Types

10. Cover-type delineation is an important component of HEP because it helps to define the study area, provides a framework for selection of evaluation species, and simplifies sampling of habitat variables. Cover types can also be important resources that must be evaluated and monitored. HEP provides the flexibility to allow users to focus on important species, cover types, or both. The following options concerning cover types can increase the efficiency of a habitat analysis:

a. Delineate cover types from aerial photographs or other remote imagery.

b. Combine similar cover types.

c. Sample only selected patches of each cover type.

d. Focus on important cover types.

Delineate cover types from aerial photographs or other remote imagery

11. An obvious way to reduce the time and expense of sampling in the field is to take full advantage of aerial photography or other forms of remote imagery for mapping surface cover types (Best 1982). Stereo pairs of color infrared photos are most useful for distinguishing vegetation types and measuring some habitat variables. Aldrich (1979) suggests that a photo scale as small as 1:750,000 can be used to map major forest stands and 1:184,000 to map other cover types. However, photos in the range of 1:10,000 to 1:100,000, depending upon the homogeneity of the area, are most useful for wildlife habitat studies.

Table 2

Techniques To Increase Efficiency and Reduce Effort in a HEP Analysis and Their Effects on Study Resolution

Option	Effect on HEP Analysis* Positive or Neutral	Negative: Reduced Accuracy or Precision	Negative: Less Information Obtained	Relevant Paragraphs
Alternatives involving cover types				
Delineate cover types from aerial photographs or other remote imagery.	X			11-13
Combine similar cover types.	X	X	X	14-18
Sample only selected patches of each cover type.		X		19-20
Focus on important cover types.			X	21-23
Alternatives involving evaluation elements				
Use available data bases to compile species lists.	X			25-26
Choose species for which models already exist.	X			27-28
Choose species whose models have already been tested.	X			29
Choose species that have simple models.	X			30-34
Choose species whose models have variables in common.	X			35
Emphasize high-priority species or guilds.			X	36-38
Select species most likely to be affected by the project.	X			39-40
Develop standardized lists of evaluation species.	X			41-45
Use community or guild models rather than species models.	X		X	46-51
Alternatives involving models				
Modify models to eliminate unnecessary variables.	X			53-58
Modify models to eliminate less important variables.		X		53-58
Focus on the limiting life requisite.	X		X	59-60
Reduce model resolution by scoring variables on a discrete scale.		X		61-76
Develop remote-sensing models.		X	X	77-80
Assign standard ratings based on cover type and condition.		X		81-82

(Continued)

* Some options can have positive, neutral, and/or negative effects depending upon extent of use.

Table 2 (Concluded)

Option	Effect on HEP Analysis: Positive or Neutral	Negative: Reduced Accuracy or Precision	Negative: Less Information Obtained	Relevant Paragraphs
Alternatives involving models (Cont.)				
Consider other ways to estimate habitat suitability.	X	X	X	83-86
Alternatives involving sampling				
Relax requirements for precision of estimates.		X		88-89
Tailor sampling effort to the shape of SI curves.	X			90-91
Use visual estimates of habitat variables.		X		92-98
Use systematic rather than random sampling designs.	X			99-100
Alternatives involving data handling and analysis				
Use a portable computer to record data in the field.	X			102-104
Use available HSI and HEP software.	X			105-107
Develop personalized computer applications.	X			108-110

12. An important consideration in cover mapping from aerial photography is the timing of the photographic flight relative to annual cycles of the vegetation. For instance, seasonal changes in the infrared reflectance of deciduous foliage make tree species more difficult to distinguish during midsummer than in fall (Aldrich 1979). Hardwood and conifer stands are differentiated most easily in the fall. Leafless conditions are better for mapping understory vegetation or for distinguishing upland from bottomland forest types; and the extent of wetlands, bodies of water, and flooded areas may change seasonally. Additional guidelines on the use and interpretation of aerial photography are given by Avery (1977, 1978).

13. In addition to imagery produced by the US Army Corps of Engineers (CE), stereo black-and-white photo coverage is often available through local offices of the Agricultural Stabilization and Conservation Service, Soil Conservation Service, or Federal and State highway departments. Offices of the Forest Service and Bureau of Land Management may have photos of their districts. Other sources of aerial and satellite photography are listed by Hays, Summers, and Seitz (1981) and Hamilton and Bergersen (1984).

Combine similar cover types

14. HEP is primarily a species-oriented evaluation method, but users are often interested in tracking the distribution and value of cover types during project construction and operation. One approach is to select several species to represent each cover type, but this can result in a very complex analysis (Roberts and O'Neil 1985a,b). One way to minimize effort is to reduce the number of cover types that are considered.

15. There are many systems for classifying surface cover types (e.g., Anderson et al. 1976, Eyre 1980, Alexander 1985); they vary greatly in resolution and in the level of effort required to produce a cover map. The more flexible and useful systems are hierarchical; they begin with broad cover categories (e.g., forest) that are then divided into increasingly detailed subcategories (e.g., maple-beech-birch type). Many of the more detailed classification systems require knowledge of the species composition of individual stands or units, which may or may not be important for a specific study.

16. For habitat studies involving HEP, there is little need to incorporate much detail into cover-type mapping. Instead, cover types should correspond to the general categories (e.g., evergreen forest, deciduous shrubland,

grassland) used by the USFWS (1981) and specified in the models for potential evaluation species. Therefore, stands of Douglas-fir (*Pseudotsuga menziesii*) and western white pine (*Pinus monticola*) would both be classified as evergreen forest, and marshes dominated by cattails (*Typha* spp.) or bulrushes (*Scirpus* spp.) would both be called herbaceous wetlands. The USFWS cover types are also much more easily mapped from aerial photographs.

17. The detail with which cover types are drawn is also related to the habitat needs of evaluation species. For example, if the species involved require only forest habitat, then only blocks of forest need to be delineated. If, however, the species also require moist areas, then riparian corridors within the forest should be mapped. Although linear features (e.g., fence-rows, hedgerows, riparian zones) or small areas (e.g., spawning beds) are difficult to map, they must be included if they are important habitat components for evaluation species. If mapped, they must be assigned to a cover type appropriate for the species using them (e.g., hedgerows might be mapped as shrubland).

18. A major purpose of cover mapping is to make sampling of habitat conditions more efficient. Sampling effort is reduced because measurements are taken only in cover types that the species of interest is known to use. In addition, habitat conditions within a cover type tend to be much more similar than those between cover types. Therefore, estimates of habitat variables are more precise if sampling is stratified by cover type. Loss of accuracy and precision can result if cover types are combined into categories that are too general. Additionally, the cover types used by a species that requires multiple cover types should not be combined.

Sample only selected patches of each cover type

19. Extensive study areas may contain many isolated patches of a cover type. This results in considerable effort if each patch is sampled to estimate the mean HSI for a species using that type. Often the amount of effort can be reduced without serious loss of information by sampling only representative patches of each cover type and applying the results to all similar patches. Ideally, patches to be sampled should be chosen at random; however, problems of access may dictate which patches are sampled.

20. An important consideration in sampling only selected patches of each cover type is that they be truly representative of all such patches in the study area. The range of variability in the sampled patches must reflect that of the entire cover type. If variability is extreme, it may be necessary to divide the cover type into subcategories and to select patches from each subcategory. For example, if the deciduous forest cover type in an area consists of many isolated woodlots that differ in age, a representative sample might consist of one or two woodlots selected at random from each of several age categories. In streams, a sample might be chosen from groups of similar reaches.

Focus on important cover types

21. The amount of effort involved in habitat evaluation often depends on the number of cover types, particularly if different evaluation species are chosen to represent each type. In diverse study areas, the species list can become long, and the number of variables to measure unmanageable. One solution is to focus on important cover types.

22. The question of importance is a judgment best made by the HEP team after considering such criteria as the extent of the cover type in the study area and vicinity, its sensitivity to alteration, the rarity of species using it, and the relative importance placed on that type at the local, regional, and national levels. Cover types can simply be ranked as high, medium, or low priority in that particular study area, perhaps using trade-off analysis such as RVIs described in USFWS (1980). The ranking of each type in another study area may be different. The level of effort can be tailored to the importance of each cover type by varying the number of evaluation species, varying the level of precision (i.e., number of samples) acceptable in estimates of model variables, or by using HSI models that are compatible with the desired level of resolution.

23. It may also be that the project will not affect all cover types, or that species or guilds selected for analysis do not use all cover types in the study area, in which case not all cover types need to be differentiated. For example, the cover types important to a featured guild of grassland residents may include only grassland, forbland, and pasture and hayland; other types need not be mapped, or they can be combined into a single "unused" category.

Evaluation Elements

24. The evaluation elements in a HEP study are usually species but can also be species life requisites, guilds, cover types, or entire communities. Some alternatives that may be appropriate to reduce the time, effort, and expense involved in a habitat analysis include the following:

- a. Use available data bases to compile species lists.
- b. Choose species for which models already exist.
- c. Choose species whose models have already been tested.
- d. Choose species that have simple models.
- e. Choose species whose models have variables in common.
- f. Emphasize high-priority species or guilds.
- g. Select species most likely to be affected by the project.
- h. Develop standardized lists of evaluation species.
- i. Use community or guild models rather than species models.

Use available data bases to compile species lists

25. Before the development and use of fish and wildlife data bases by a growing number of agencies, HEP users had to consult the literature, ask people familiar with the area, or conduct costly field surveys to compile lists of species likely to use a project area. This can be a formidable task; bird species alone often number in the hundreds.

26. Fish and wildlife information systems are computerized lists of species present within a state or region. The USFWS was an early supporter of the development of information systems by individual states. Systems patterned after USFWS guidelines include information on species distribution, habitat requirements, food habits, beneficial management practices, and status, as well as selected references. These data bases can be searched rapidly using key words; for example, it is a simple task to obtain a list of all species found in cold lacustrine waters or upland hardwood stands in a particular area. Currently, at least 18 states (Alabama, California, Colorado, Illinois, Kansas, Kentucky, Maryland, Missouri, New Jersey, New York, Pennsylvania, South Carolina, Tennessee, Utah, Virginia, Washington, Wisconsin, and Wyoming) are using or developing fish and wildlife information systems, and more are expected in the future (Waldon 1987). Because of the

widespread distribution of many vertebrates, information from a nearby state may be useful in states that have not yet developed their own systems. Access to a data base can usually be arranged through that state's wildlife agency. In addition, other agencies and organizations, including some CE Districts, have independently developed computerized data bases, and published references are available for some state and Federal agency jurisdictions (e.g., Stiles 1978, DeGraaf and Rudis 1986). An important source of information on the distribution of rare plants and animals is the Natural Heritage Program affiliated with the wildlife agencies of most states.

Choose species for which models already exist

27. Construction of HSI models can be lengthy and difficult. Model construction generally involves an exhaustive literature search, identification of important habitat variables, development of a logical model structure, and documentation of assumptions and instructions for use. New models should be reviewed by experts on the species and must be tested in the field to determine whether they work correctly.

28. For most HEP studies, it is possible to avoid the model-development process by selecting from the expanding pool of published and unpublished models. O'Neil and Gray (1988) (in O'Neil 1985) list 131 models for species of birds, mammals, reptiles, and amphibians and 75 models for fish, shellfish, and other invertebrates. The list includes approximately 150 HSI models published in the USFWS bluebook series. Additional models are available from the US Forest Service, state fish and wildlife agencies, and other sources.

Choose species whose models have already been tested

29. In spite of the relatively large number of HSI models that have been developed and published, few have been tested. Thus, the reliability of most models is unknown. For best results, models should be tested before being used to guide major land-use decisions, preferably in the region or environment in which they will be applied. Because this is a time-consuming process, habitat analyses can be hastened considerably by using models that have already been tested in areas similar to those being studied. The USFWS supports a computerized Habitat Model Reference Library (HMRL) containing

testing information plus additional comments from field users of individual HSI models. The HMRL is housed at the National Ecology Research Center in Fort Collins, CO. The HMRL may be accessed by modem at (303) 226-9365, or contact Jon Richards or Warren Mangus, telephone (303) 226-9335 or 9293, respectively. The mailing address is National Ecology Research Center, 2627 Redwing Road, Fort Collins, CO 80526-2899.

Choose species that have simple models

30. HSI models vary considerably in complexity and ease of use. One determinant of model complexity is the number of variables it contains. Although some habitat variables can be measured quickly and easily from maps or aerial photographs, most variables must be measured in the field. Therefore, each variable adds to the field effort involved in a habitat evaluation.

31. For terrestrial species, models in the USFWS bluebook series contain as few as 2 and as many as 13 variables, depending on the habitat type in which the model is applied (Table 3). Models for aquatic species and invertebrates contain as many as 20 variables (Table 4). Models for terrestrial species that require more than one cover type also incorporate interspersion calculations that increase model complexity. Tables 3 and 4 can be used in the selection of evaluation species to reduce the number of variables that must be measured.

32. Another consideration in applying a model is the ease of measuring individual habitat variables. Variables that can be taken from maps or aerial photographs are often easiest to measure; however, models that are based completely on remotely sensed data usually give results that are less reliable than those incorporating field measurements. Remote sensing models are most appropriate for low-resolution assessments of relatively large study areas (Payne and Long 1986).

33. The easiest variables to estimate in the field are those involving presence or absence of habitat features (e.g., presence of herbaceous vegetation) or discrete scales (e.g., substrate type). Estimates of coverage (e.g., percent cover of shrubs) are relatively easy to make by point sampling. Estimates of density are more time consuming, particularly for abundant small features (e.g., density of shrub stems). Some variables require complex sampling schemes (e.g., biomass of woody browse) or intermediate calculations (e.g., tree canopy volume). A considerable amount of time can be saved by

Table 3

Number of Habitat Variables Contained in the HSI Models
for Birds, Mammals, Reptiles, and Amphibians
Published in the USFWS Bluebook Series

Common Name*	Number of Variables**	Interspersion Calculations	Publication Number †
American alligator	4-5	--	82(10.136)
American black duck	3-4	--	82/10.68
American coot	3	--	82(10.115)
American woodcock	4	--	82(10.105)
Baird's sparrow	2	--	82/10.44
Bald eagle	3-4	--	82(10.126)
Barred owl	3	--	82(10.143)
Beaver	6-8	--	82/10.30A
Belted kingfisher	5-6	--	82(10.87)
Black bear	8	--	82(10.144)
Black brant	2	--	82/10.63
Black-capped chickadee	2-3	--	82/10.37
Black-shouldered kite	4	--	82(10.130)
Blue grouse	7	Yes	82/10.81
Blue-winged teal	4	Yes	82(10.114)
Bobcat	2	--	82(10.147)
Brewer's sparrow	6	--	82/10.83
Brown thrasher	3	--	82(10.118)
Bullfrog	11	--	82(10.138)
Cactus wren	2	--	82(10.96)
Canvasback	3	Yes	82/10.82
Clapper rail	3	--	82/10.51
Downy woodpecker	2	--	82/10.38
Eastern brown pelican	4	--	82(10.90)
Eastern cottontail	4	--	82/10.66
Eastern meadowlark	5	--	82/10.29
Eastern wild turkey	5-13	Yes	82(10.106)

(Continued)

* See Appendix A for scientific names.

** Numbers vary depending on the habitat type in which the model is applied or the version of the model when multiple versions are given. Only the number of unique variables is shown.

† USFWS publication number. Numbers denoted by 82/10.xx are in the FWS/OBS series; those denoted by 82(10.xx) are in the Biol. Rep. series.

(Sheet 1 of 3)

Table 3 (Continued)

Common Name	Number of Variables	Interspersion Calculations	Publication Number
Ferruginous hawk	3-5	Yes	82/10.10
Field sparrow	4	--	82/10.62
Fisher	4	--	82/10.45
Forster's tern (breeding)	5	--	82(10.131)
Fox squirrel	5	--	82/10.18
Gadwall	4	Yes	82(10.100)
Gray partridge	8	--	82(10.73)
Gray squirrel	4	--	82/10.135
Great blue heron	6	--	82(10.99)
Great egret	2-4	--	82/10.78
Greater prairie chicken	4	Yes	82(10.102)
Greater sandhill crane	4	--	82(10.140)
Greater white-fronted goose	2-5	--	82(10.116)
Hairy woodpecker	4	--	82(10.146)
Lark bunting	4	--	82(10.137)
Laughing gull	8	--	82(10.94)
Least tern	5	--	82(10.103)
Lesser scaup (breeding)	5	--	82(10.117)
Lesser scaup (wintering)	4	--	82(10.91)
Lesser snow goose	4	--	82(10.97)
Lewis' woodpecker	2-5	--	82/10.32
Mallard (wintering)	3-11	Yes	82(10.132)
Marsh wren	4	--	82(10.139)
Marten	4	--	82/10.11
Mink	3-4	--	82(10.127)
Mottled duck	8	--	82/10.52
Muskrat	3-6	--	82/10.46
Northern bobwhite	7-9	Yes	82(10.104)
Northern pintail (wintering)	4-5	--	82(10.121)
Northern pintail (breeding)	4	Yes	82(10.145)
Pileated woodpecker	5	--	82/10.39
Pine warbler	3	--	82/10.28
Plains sharp-tailed grouse	5	Yes	82(10.142)
Pronghorn	6	--	82/10.65

(Continued)

(Sheet 2 of 3)

Table 3 (Concluded)

Common Name	Number of Variables	Interspersion Calculations	Publication Number
Red-spotted newt	3-6	--	82(10.111)
Red-winged blackbird	1-5	--	82(10.95)
Redhead	3	--	82/10.53
Roseate spoonbill	3-4	--	82/10.50
Ruffed grouse	6	--	82(10.86)
Slider turtle	5	--	82(10.125)
Snapping turtle	7	--	82(10.141)
Snowshoe hare	2	--	82(10.101)
Southern red-backed vole	4	--	82/10.42
Spotted owl	3	--	82(10.113)
Swamp rabbit	2-3	--	82(10.107)
Veery	5	--	82/10.22
Western grebe	8	--	82/10.69
White ibis	3-4	--	82(10.93)
White-tailed deer*	2-3	--	82(10.123)
Williamson's sapsucker	4	--	82/10.47
Wood duck	1-7	Yes	82/10.43
Yellow warbler	3	--	82/10.27
Yellow-headed blackbird	4	--	82/10.26

* Variables may be repeated for each forage type.

(Sheet 3 of 3)

Table 4

Number of Habitat Variables Contained in the HSI Models for Fish and Shellfish Published in the USFWS Bluebook Series

Common Name*	Number of Variables**	Publication Number†
Alewife	5	82/10.58
American oyster	6	82/10.57
American shad	2-3	82(10.88)
Arctic grayling	10	82(10.110)
Atlantic croaker	4-6	82/10.98
Bigmouth buffalo	10-11	82/10.34
Black bullhead	11-13	82/10.14
Black crappie	11-12	82/10.6
Blacknose dace	2-16	82/10.41
Blueback herring	5	82/10.58
Bluegill	13-15	82/10.8
Brook trout	7-17	82/10.24
Brown shrimp	4	82/10.54
Brown trout	3-18	82(10.124)
Channel catfish	11-12	82/10.2
Chinook salmon	17	82(10.122)
Chum salmon	9	82(10.108)
Coho salmon	15	82/10.49
Common carp	11-12	82/10.12
Common shiner	6-9	82/10.40
Creek chub	20	82/10.4
Cutthroat trout	8-17	82/10.5
English sole (juvenile)	5	82(10.133)
Fallfish	2-6	82/10.48
Flathead catfish	6-10	82(10.152)
Gizzard shad	7	82(10.112)
Green sunfish	11-13	82/10.15
Gulf flounder	4	82(10.92)
Gulf menhaden	9	82/10.23

(Continued)

* See Appendix A for scientific names.

** Numbers vary depending on the habitat type in which the model is applied. Only the number of unique variables is shown.

† USFWS publication number. Numbers denoted by 82/10.xx are in the FWS/OBS series; those denoted by 82(10.xx) are in the Biol. Rep. series.

Table 4 (Concluded)

Common Name	Number of Variables	Publication Number
Hard clam	6	82/10.77
Inland silverside	7	82(10.120)
Lake trout	3-5	82/10.84
Largemouth bass	13-15	82/10.16
Littleneck clam	3	82/10.59
Longnose dace	4-6	82/10.33
Longnose sucker	5-13	82/10.35
Muskellunge	11	82(10.148)
Northern pike	7-9	82/10.17
Paddlefish	10	82/10.80
Pink salmon	11	82(10.109)
Pink shrimp	5	82/10.76
Rainbow trout	7-18	82/10.60
Red drum	4-5	82/10.74
Redbreast sunfish	10	82(10.119)
Redear sunfish	9-10	82/10.79
Shortnose sturgeon	6	82(10.129)
Slough darter	4-8	82/10.9
Smallmouth bass	12-13	82/10.36
Smallmouth buffalo	12-13	82/10.13
Southern flounder	4	82(10.92)
Southern kingfish	2-8	82/10.31
Spot	5	82/10.20
Spotted bass	9-10	82/10.72
Spotted seatrout	5	82/10.75
Striped bass (coastal)	11	82/10.1
Striped bass (inland)	3-4	82/10.85
Walleye	13-14	82/10.56
Warmouth	7-10	82/10.67
White bass	8	82(10.89)
White crappie	11-12	82/10.7
White shrimp	4	82/10.54
White sucker	6-10	82/10.64
Yellow perch	7-8	82/10.55

examining alternative models and selecting those containing a small number of easily measured variables, if the species are appropriate to the objectives of the study.

34. Another determinant of model complexity is the form in which the model is written. Biologists in Missouri have developed HSI models in a simple question/answer format for 30 species (Urich, Graham, and Cook 1983; Urich and Graham 1984). The use of word models is also addressed by the USFWS (1981). In addition, paragraphs 61-76 of this document offer suggestions on altering the form of variables to make models easier to use.

Choose species whose models have variables in common

35. Species living in the same environment often respond to the same habitat features, although they may respond in different ways. Therefore, HSI models for animals occupying the same cover type often share some of the same variables. One way to reduce the amount of sampling in a habitat assessment is to select evaluation species whose models have variables in common. For example, the eastern wild turkey and gray squirrel (see Appendix A for scientific names) are possible evaluation species for eastern deciduous forests. Although the squirrel model contains 4 variables and the turkey model up to 13 (Table 3), the amount of sampling effort is reduced because they have 3 variables in common (availability of hard mast-producing trees, percent tree canopy cover, and average diameter at breast height (dbh) of overstory trees). This approach may be especially useful for aquatic species; Miller et al. (1987a) found many overlapping variables among models for 12 species of fish.

Emphasize high-priority species or guilds

36. Just as cover types can differ in value or importance, different species or species groups do not have to be given equal emphasis in a habitat evaluation. Considerable time and expense may be saved if the analysis is focused on high-priority species.

37. The relative importance of fish and wildlife species should be determined locally and may be based on their ecological value, scarcity in the region or nation, esthetic qualities, or economic value to local residents. A determination of importance should also consider traditional or anticipated

uses for the populations in the project area. For example, the white-tailed deer may be a high-priority species in a public hunting area, whereas cavity-nesting songbirds may be more valuable in an area set aside as a nature preserve.

38. There are two ways to focus a habitat evaluation on high-priority species or guilds. One is to include only those species in the assessment. This is a logical choice for use in areas that will be managed exclusively for the benefit of that species or guild (e.g., refuges for red-cockaded woodpeckers or wintering raptors). The second way is to shift most of the sampling effort toward the priority species and settle for a low-resolution evaluation of the less important species. This might be done by using low-resolution HSI models on the low-priority species or by relaxing standards of precision in estimates of habitat variables, thereby reducing sample sizes or allowing visual estimates.

Select species most likely to be affected by the project

39. This recommendation will be obvious to most users of HEP; the primary difficulty lies in identifying the vulnerable species. For example, a change in hydrologic regime has straightforward effects on water-dependent animals, such as salamanders or muskrats. Similarly, thinning or removing overstory trees in a deciduous forest obviously affects those species of birds that use the canopy layer for reproduction or foraging. But forest thinning may also have indirect impacts on other species that are strictly ground dwellers by altering the microclimate of the forest floor or reducing the availability of food items produced in the canopy. Thus, altering the canopy layer may affect white-tailed deer by reducing mast production and red-spotted newts by allowing too much sunlight to reach the ground.

40. To select species that may be vulnerable to a particular impact, first determine which habitat variables will be affected by the project. In the example above, the affected variables might include percent canopy cover, overstory tree density, and density of mast-producing trees. Then, select species or guilds whose HSI models incorporate those variables.

Develop standardized lists of evaluation species

41. The process of selecting evaluation species, then justifying and documenting that choice, can be very time consuming. This is particularly true if potential evaluation species must first be arranged into one or more guild matrices based on their needs for reproduction, foraging, and escape habitats. Frequent users of HEP can reduce this repetitious activity by developing standardized lists of evaluation species that can be used repeatedly in a region or for projects having similar impacts.

42. A standard list need not be static. For example, biologists with the USFWS in Vero Beach, FL, developed a list of 48 species of greatest importance in the area.* Criteria for ranking species were agreed upon by other local biologists and included rarity in the area, degree of vulnerability to impacts, and economic importance. For a particular project, the user selects the highest ranking species that use the affected cover types. The list acts both as a checklist and a decision-making tool.

43. There are additional benefits to using the same set of evaluation species in a number of HEP studies. Because the results of a habitat assessment depend upon the species used, estimates of habitat quality based on the same evaluation elements are more consistent and comparable from study to study. This can give a clearer picture of the range of habitat conditions at different sites, which is particularly valuable for management-oriented studies. By using the same HSI models repeatedly, the user gains greater familiarity and confidence with them and increases the reliability and repeatability of habitat assessments. Furthermore, only a small number of models need to be tested and modified for use in a particular region.

44. Standardized lists of evaluation species can be compiled for each of the important cover types in a region. Further economies can be made by emphasizing models containing few variables or those having variables in common. The goal should be to limit the effort involved in a habitat assessment to a small number of easily measured habitat variables.

45. The selection of evaluation species also depends on the objectives of the habitat assessment and the anticipated uses of the land. Therefore, it

* Personal Communication, October 1986, Arnold Banner, Fish and Wildlife Biologist, US Fish and Wildlife Service, Vero Beach, FL.

will not be possible to use the same species in all studies. However, most HEP studies strive for a broad ecological assessment of project lands. These analyses are particularly suitable for the development of a standardized roster of evaluation species.

Use community or guild models rather than species models

46. Evaluation elements in a HEP analysis generally are species but may also be guilds or communities. The use of guild or community models offers many advantages for reduced-effort habitat evaluations, including fewer variables to sample, faster application, a more holistic perspective, and a single numerical result rather than one for each species. Unfortunately, few community models are available, so interested users may have to develop their own.

47. Whereas species-oriented HSI models are designed to estimate long-term potential carrying capacity of the habitat for a species, community models usually are designed to predict species richness or diversity of the fish or wildlife community occupying an area (Schroeder 1987). Therefore, a single model may be used to assess the broad impacts of project development on the community. By focusing on diversity, community models may have the disadvantage of overlooking changes in the species composition of the community.

48. The Habitat Evaluation System (US Army Corps of Engineers 1980) is a community-level approach designed to assess the overall suitability for wildlife of cover types in the Lower Mississippi Valley, considering both diversity and population levels. Its models (currently being revised) are similar to standard HSI models and can also be used with HEP. Habitat suitability is estimated from variables measured onsite (e.g., number of mast-bearing trees, percent ground cover). Short (1984) developed two models whose outputs reflect the structural diversity of habitats. One was based on the number of wildlife guilds an area can support relative to the maximum number of guilds in the most diverse habitat in the region. The second model was based on the number of habitat layers in the project area. Hench et al. (1985) also used layers for predicting the effects of land-use changes on wildlife, placing species in layers within successional stages of plant communities. Additional community-level models include regional models for Illinois (Graber and Graber 1976) and Texas (Frye 1984), portions of a wetland

evaluation method (Adamus et al. 1987), a stream corridor assessment technique (Garcia et al. 1984), a model for species richness in shelterbelts (Schroeder 1986), and a model for gravel bar mussel communities (Miller et al. 1987b).

49. One approach to the development of guild models is to group species according to the variables in their HSI models (Payne and Long 1986, Miller et al. 1987a). Miller et al. (1987a) developed "multispecies" HSI models for fish by averaging the suitability curves of closely related species that had similar habitat requirements. The multispecies models could then be used whenever a low-resolution assessment was desired for that group of species.

50. Guild or community models can be developed from information in the literature. The models should then be tested to make sure they work properly. For example, there is abundant literature on the factors affecting diversity of bird communities in a variety of habitats. A model predicting bird diversity in forested areas might include as variables the number of tree species, density of foliage in various habitat layers, canopy cover and height, and abundance of snags (e.g., Willson 1974, Balda 1975, James and Wamer 1982).

51. Community models based on diversity have some disadvantages when used with the standard HEP accounting system. First, there is the problem that larger areas contain more species. Because diversity is already area-dependent, it makes little sense to multiply the HSI value by the acreage of the site to calculate HUs in the standard way. Second, it is not readily apparent what a change in HSI (i.e., diversity) means in terms of the species involved. Changes in HUs for individual species are readily converted into potential numbers of animals gained or lost. Changes in community HSI values are not as easily interpreted. Finally, because of the ambiguous units by which diversity is quantified, it may be difficult to develop mitigation plans or trade-off alternatives for losses of wildlife diversity.

Models

52. The heart of a HEP study is the determination of habitat suitability either through the use of HSI models or by other means. There are several ways to reduce the effort involved in estimating HSI, especially when a low-resolution result will suffice. The following alternatives involve modification of existing models or development of new ways to determine habitat suitability:

a. Modify models to eliminate unnecessary or less important variables.

b. Focus on the limiting life requisite.

c. Reduce model resolution by scoring variables on a discrete scale.

d. Develop remote-sensing models.

e. Assign standard ratings based on cover type and condition.

f. Consider other ways to estimate habitat suitability.

Modify models to eliminate unnecessary or less important variables

53. A model that contains a large number of variables may not be very sensitive to changes in one or more of them. Furthermore, the project site where the model will be applied may be fairly homogeneous with respect to one or more model variables or may entirely lack certain features included in the model. In these situations, variables can often be eliminated without affecting model performance appreciably.

54. A simple sensitivity analysis is the best way to determine the relative importance of variables in a model for a particular application. To check the sensitivity of a model, first calculate the HSI that results when all variables are fixed at values that reflect the anticipated average conditions on the study area. Next, calculate HSI values when the first variable (V1) is set at (a) the highest and (b) the lowest value that is likely in the study area, leaving all other variables fixed. Repeat the procedure using the anticipated extreme values of the second variable (V2), leaving all other variables, including V1 , fixed at average values. Repeat for the other variables in the model. The variables can then be ranked according to the magnitude of the change they produced in the predicted HSI. Variables that caused little change in HSI are likely candidates for elimination. Use of the sensitivity analysis of the USFWS HSI software may assist the user in this effort.

55. Another way to identify variables that might be deleted is to examine the model in the light of personal knowledge of the species concerned. The user may already be familiar with the habitat needs of a species and may know which variables are most important. The documentation accompanying the model should also identify the critical habitat features.

56. Finally, the shape of the suitability curves and the form of the equation for calculating HSI can give clues to the relative importance of variables to the model. A curve that shows a limited range of suitability index (SI) values (i.e., SI does not range all the way from 0 to 1.0) may indicate a variable to which the model is less sensitive. Other curves may predict constant SI over a broad range of the habitat variable; these variables might be dropped, particularly if anticipated values from the study area fall mostly within the zone of constant SI. For example, dissolved oxygen in a coldwater stream may never drop below the level where $SI = 1.0$. In addition, important variables may be weighted more heavily in the equation used to calculate HSI; that is, they will have larger coefficients or exponents.

57. Any modified model should be tested before it is used in a HEP study. There are two ways to test a model that was produced by eliminating variables from a preexisting model. The first is to compare the predictions of the original and modified models by using them with hypothetical data. This approach is best done by using a microcomputer and statistical software to produce large, randomly generated data sets for each variable, calculating HSI values with both models, and comparing the results (this technique is used later in this report to test discrete versions of HSI models). The approach assumes that the original, unmodified model is correct. If the original model has never been tested, then the following technique is recommended.

58. O'Neil et al. (1988) outline a procedure for testing and modifying HSI models. This procedure involves the selection of a number of study plots representing a range of habitat conditions for the species, measurement of habitat variables on each plot, and calculation of HSI values. The results of the model are then compared with a standard that reflects habitat quality. The standard of comparison is determined for each study plot and could be based on long-term population levels, measurements of habitat use, habitat suitability ratings given by species experts, or reproductive rates or other indicators of animal well-being (Schamberger and O'Neil 1986). A model that performs poorly is modified until its predicted HSI scores correlate more closely with the standard.

Focus on the limiting life requisite

59. Many HSI models are composed of submodels that describe the suitability of habitats for one or more important life requisites, such as feeding

and reproduction. Suitability indices for each life requisite are then combined in some way to estimate the overall HSI. For example, the model for eastern wild turkeys (Schroeder 1985) in forest cover types consists of three life requisites: (a) summer food/brood habitat; (b) fall, winter, and spring food; and (c) cover. These requisites are described by 2, 5, and 3 variables, respectively, for a total of 10 habitat variables. Therefore, use of this one model in a HEP study could involve a considerable expenditure of time, effort, and funds.

60. In certain study areas, the shortage of one life requisite may limit potential populations even though other requisites are abundant. Depending on study objectives, a HEP study need focus only on the limiting life requisite, with default scores assigned to the other requisites. For example, a deciduous forest containing many shrubs and mast-bearing trees may provide excellent cover and fall, winter, and spring food supplies for turkeys, but the shortage of herbaceous cover may limit the production of broods. To evaluate the quality of this area for turkeys, it is necessary to assess only the summer food/brood habitat life requisite. This reduces the number of variables to be measured from 10 to 2, considerably reducing sampling effort and simplifying interpretation of the results.

Reduce model resolution by scoring variables on a discrete scale

61. Most HSI models are composed of variables that are measured on a continuous scale (e.g., percent ground cover, dbh of overstory trees, velocity of current). These variables are converted by the suitability curves in the model to SI values that are also continuous; that is, they can take any value from 0 to 1.0. One way to reduce the resolution and simplify the sampling effort involved in a habitat evaluation is to convert existing HSI model curves from continuous to discrete forms.

62. Procedure to simplify HSI models. One way to produce discrete versions of HSI models is to reduce the SI for each variable to only three categories: (a) zero (when SI = 0), (b) low (when 0 < SI < 0.5), and (c) high (when SI ≥ 0.5). This means that the habitat variable itself is also divided into categories corresponding to the three levels of suitability; the break points between suitability levels are determined by examining the appropriate curve in the original model.

63. For example, Figure 1 shows a hypothetical but typical SI curve. The first step in creating a discrete version of this relationship is to draw a horizontal line corresponding to an SI of 0.5. The point (or points) at which this line cuts the SI curve is then projected downward to the horizontal axis. The ranges of the habitat variable corresponding to each level of suitability are then read off the horizontal axis. In this example, values of the variable between 0 and 20 percent have zero suitability, values between 20 and 60 percent have low suitability, and values above 60 percent have high suitability. The procedure is then repeated for the other variables in the model whose SI curves are continuous; variables that are already categorical (e.g., successional stage, substrate type) need not be altered.

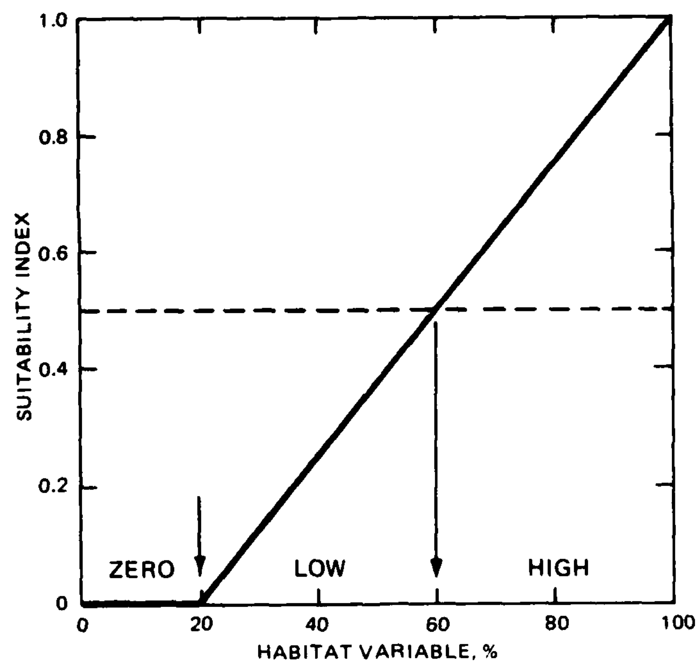

Figure 1. Hypothetical continuous SI curve showing the method used to convert it to a discrete version. The habitat variable is scored in three categories: zero, where SI = 0 ; low, where 0 < SI < 0.5 ; and high, where SI ≥ 0.5

64. After the suitability ratings for each variable on a site have been determined in the field, a standard numeric SI score is assigned to each rating. For suitability ratings of zero, low, and high as described above, numeric scores of 0, 0.2, and 0.9 are recommended. The HSI is then calculated in the usual way, by combining SI values using the equation specified in the model. For the models that have been examined, this approach produces an HSI value that is within 0.2 of that calculated with the original model 90 percent of the time.

65. Example: the red-backed vole. The HSI model for the southern red-backed vole in the western part of its range (Allen 1983) contains four habitat variables (V1-V4), each described by a continuous SI curve (Figure 2). The following equation is used to aggregate SI values:

$$HSI = (SI1 \times SI2 \times SI3)^{1/3} \times SI4 \qquad (1)$$

66. A simplified, discrete version of the model is produced by examining each SI curve and defining ranges of each habitat variable in which the SI is either zero (SI = 0), low (0 < SI < 0.5), or high (SI ≥ 0.5). In the field, sites are scored "0" if suitability is zero, "L" if suitability is low, and "H" if suitability is high. Therefore, the model can be rewritten as follows:

Variable	SI Score	Definition
V1	0	average dbh of overstory trees is 0 cm
	L	average dbh of overstory trees is >0 but <15 cm
	H	average dbh of overstory trees is ≥15 cm
V2	0	percent ground surface covered by downfall is 0%
	L	percent ground surface covered by downfall is >0 but <10%
	H	percent ground surface covered by downfall is ≥10%
V3	0	percent grass canopy cover is ≥80%
	L	percent grass canopy cover is >45 but <80%
	H	percent grass canopy cover is ≤45%
V4	L	percent canopy closure of evergreen trees is ≤33%
	H	percent canopy closure of evergreen trees is >33%

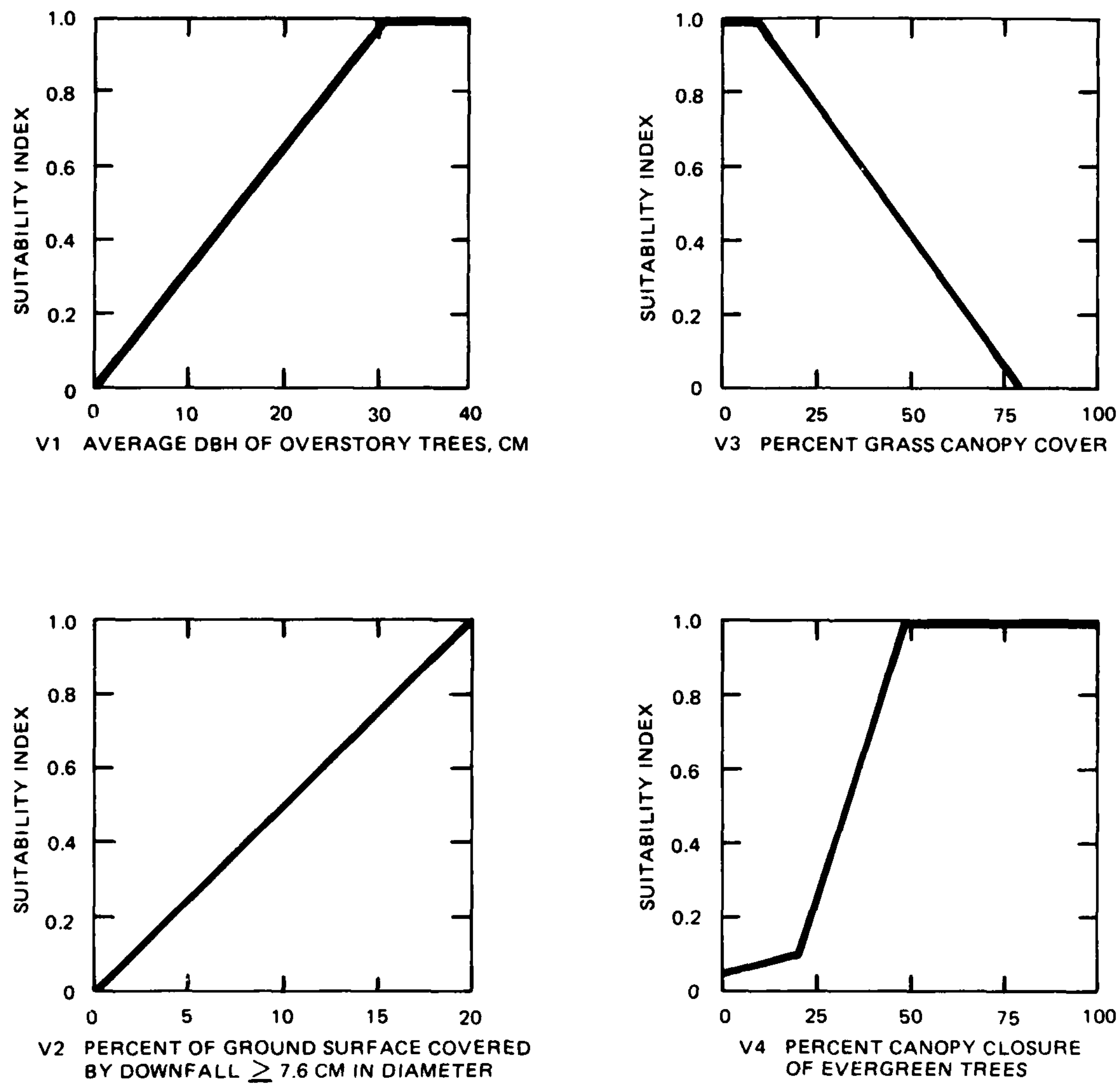

Figure 2. SI curves contained in the HSI model for the southern red-backed vole (Allen 1983)

HSI is calculated by Equation 1 and substituting numeric values of 0, 0.2, and 0.9 for suitability ratings of "0," "L," and "H," respectively.

67. To determine the best numeric scores to assign to habitat suitability ratings produced by a discrete model, various scores were tried in the red-backed vole model. For habitats of "low" suitability, numeric scores of 0.1, 0.2, 0.3, and 0.4 were tested. Scores of 0.8, 0.9, and 1.0 were tried for suitability ratings of "high." The values used in the example above (0.2 for "low," 0.9 for "high") produced the smallest difference between HSIs predicted by the discrete and original versions of the model.

68. Many HSI models are also very sensitive to zero values for the SIs. Those incorporating products and geometric means in their aggregation equations return an HSI of zero whenever any one of the component SI values is zero. Therefore, it is important in developing a discrete HSI model that unsuitable values for the variables be given a numeric score of 0.

69. A test of the discrete model. The discrete version of the red-backed vole HSI model was tested by comparing its results with those of the original, unmodified model. Data for 1,000 hypothetical field sites were produced by generating uniform random numbers for each habitat variable. Randomly generated values ranged from 0 to 50 cm for $V1$, 0 to 30 percent for $V2$, and 0 to 100 percent for $V3$ and $V4$.

70. Tables 5 and 6 show SIs or ratings and HSI values calculated with the original and discrete models, respectively. For all 1,000 sites, the difference between HSI values produced by the two models averaged 0.007 (range -0.298 to 0.451) with a standard deviation of 0.111. For 90 percent of the sites, the discrete form of the model produced an HSI value within 0.183 of that produced by the original model. The correlation between the original and modified HSI values was $r = 0.929$.

71. A discrete version of the HSI model for wintering American woodcock in forest habitats was derived from the original model (Cade 1985) and tested in the manner described previously. All variables except $V1$ were made categorical; $V1$ (soil texture and drainage class) was already categorical and was not changed. The predicted HSI for the discrete model was highly correlated with that of the original model ($r = 0.964$, $n = 1,000$). The average difference between HSI scores was -0.012 (SD = 0.083, range = -0.393 to 0.400). Therefore, the discrete model predicted an HSI within 0.137 of that predicted by the original model 90 percent of the time.

Table 5

Variables, SIs, and HSI Values Calculated with the Original Model for the Southern Red-Backed Vole

Site*	Variable V1	Variable V2	Variable V3	Variable V4	SI SI1	SI SI2	SI SI3	SI SI4	HSI
1	26	19	43	48	0.87	0.95	0.53	0.94	0.712
2	47	16	33	6	1.00	0.80	0.67	0.07	0.053
3	49	27	64	24	1.00	1.00	0.23	0.22	0.135
4	5	5	57	21	0.17	0.25	0.33	0.13	0.031
5	45	22	80	4	1.00	1.00	0.00	0.06	0.000
6	0	9	6	68	0.00	0.45	1.00	1.00	0.000
7	2	28	23	92	0.07	1.00	0.81	1.00	0.379
8	25	4	14	69	0.83	0.20	0.94	1.00	0.540
9	19	19	10	20	0.63	0.95	1.00	0.10	0.084
10	45	3	99	56	1.00	0.15	0.00	1.00	0.000
11	24	1	29	52	0.80	0.05	0.73	1.00	0.308
12	4	20	53	21	0.13	1.00	0.39	0.13	0.048
13	16	16	55	74	0.53	0.80	0.36	1.00	0.534
14	47	20	66	34	1.00	1.00	0.20	0.52	0.304
15	26	20	31	29	0.87	1.00	0.70	0.37	0.313
16	5	5	24	19	0.17	0.25	0.80	0.10	0.031
17	10	14	14	8	0.33	0.70	0.94	0.07	0.042
18	49	28	52	72	1.00	1.00	0.40	1.00	0.737
19	21	17	41	82	0.70	0.85	0.56	1.00	0.692
20	24	20	48	46	0.80	1.00	0.46	0.88	0.629
21	38	18	40	95	1.00	0.90	0.57	1.00	0.801
22	16	26	92	60	0.53	1.00	0.00	1.00	0.000
23	2	0	52	9	0.07	0.00	0.40	0.07	0.000
24	38	12	38	96	1.00	0.60	0.60	1.00	0.711
25	34	2	99	3	1.00	0.10	0.00	0.06	0.000
26	5	9	80	96	0.17	0.45	0.00	1.00	0.000
27	12	2	87	9	0.40	0.10	0.00	0.07	0.000
28	10	20	8	7	0.33	1.00	1.00	0.07	0.047
29	16	5	52	56	0.53	0.25	0.40	1.00	0.376
30	13	28	33	90	0.43	1.00	0.67	1.00	0.663
31	49	0	90	84	1.00	0.00	0.00	1.00	0.000
32	42	25	80	69	1.00	1.00	0.00	1.00	0.000
33	26	17	68	83	0.87	0.85	0.17	1.00	0.502
34	22	21	6	42	0.73	1.00	1.00	0.76	0.685
35	8	23	[illegible]	34	0.27	1.00	0.49	0.52	0.263
36	15	19	[illegible]	49	0.50	0.95	0.79	0.97	0.698
37	39	15	59	26	1.00	0.75	0.30	0.28	0.170
38	16	8	98	55	0.53	0.40	0.00	1.00	0.000
39	39	8	31	31	1.00	0.40	0.70	0.43	0.281
40	28	20	35	38	0.93	1.00	0.64	0.64	0.540

* Only the first 40 of 1,000 sites are shown.

Table 6

Suitability Ratings and HSI Values Calculated with the Discrete Version of the Red-Backed Vole HSI Model

	Suitability Rating					
Site*	Score 1	Score 2	Score 3	Score 4	Modified HSI**	Difference†
1	H	H	H	H	0.810	0.098
2	H	H	H	L	0.180	0.127
3	H	H	L	L	0.109	-0.025
4	L	L	L	L	0.040	0.009
5	H	H	0	L	0.000	0.000
6	0	L	H	H	0.000	0.000
7	L	H	H	H	0.491	0.112
8	H	L	H	H	0.491	-0.049
9	H	H	H	L	0.180	0.096
10	H	L	0	H	0.000	0.000
11	H	L	H	H	0.491	0.183
12	L	H	L	L	0.066	0.018
13	H	H	L	H	0.491	-0.044
14	H	H	L	H	0.491	0.187
15	H	H	H	L	0.180	-0.133
16	L	L	H	L	0.066	0.035
17	L	H	H	L	0.109	0.067
18	H	H	L	H	0.491	-0.246
19	H	H	H	H	0.810	0.118
20	H	H	L	H	0.491	-0.139
21	H	H	H	H	0.810	0.009
22	H	H	0	H	0.000	0.000
23	L	0	L	L	0.000	0.000
24	H	H	H	H	0.810	0.099
25	H	L	0	L	0.000	0.000
26	L	L	0	H	0.000	0.000
27	L	L	0	L	0.000	0.000
28	L	H	H	L	0.109	0.062
29	H	L	L	H	0.297	-0.079
30	L	H	H	H	0.491	-0.172

(Continued)

* Only the first 40 of 1,000 sites are shown. Values of variables are as in Table 5.

** Calculated by substituting 0 for "0," 0.2 for "L," and 0.9 for "H."

† Equals the difference between the HSI values calculated with the original and discrete models (modified HSI - original HSI). See Table 5 for original HSI values.

Table 6 (Concluded)

	Suitability Rating					
Site	Score 1	Score 2	Score 3	Score 4	Modified HSI	Difference
31	H	0	0	H	0.000	0.000
32	H	H	0	H	0.000	0.000
33	H	H	L	H	0.491	-0.011
34	H	H	H	H	0.810	0.125
35	L	H	L	H	0.297	0.034
36	H	H	H	H	0.810	0.112
37	H	H	L	L	0.109	-0.061
38	H	L	0	H	0.000	0.000
39	H	L	H	L	0.109	-0.172
40	H	H	H	H	0.810	0.270

72. Discussion. The advantage of HSI models with discrete variables is that they require much less sampling effort than the original models. It is not necessary to estimate the value of each habitat variable, only to determine into which category it falls. Detailed field measurements are therefore unnecessary, except to resolve borderline cases. Visual estimates of habitat variables are sufficient whenever the value of a variable clearly falls within a particular category.

73. Simplified models are advantageous only when they reduce sampling effort. If it is not possible to estimate a variable visually (e.g., dissolved oxygen), it will not help much to simplify its suitability curve. However, a single model can contain both discrete and continuous suitability functions for different variables.

74. A modified model will mimic the original model even more closely if more than three suitability levels are used. For example, a four-level version of the vole model with suitability categories of zero (SI = 0), low ($0 < SI < 0.33$), medium ($0.33 \le SI < 0.67$), and high ($SI \ge 0.67$), and arbitrarily assigned suitability scores of 0, 0.2, 0.5, and 0.9, respectively, produced HSI values that differed from those of the original model by an average of 0.002 with a 90-percent confidence interval between -0.133 and 0.137 (range -0.200 to 0.254). Although the performance of this modified model was better than that of the three-level version presented earlier, it may be more difficult and time-consuming to use because of the increased number of borderline cases requiring additional sampling to resolve.

75. The question of how close is close enough for agreement between the simplified and original model must be decided by the user in light of his or her objectives and the consequences of error. In a small percentage of cases, differences can be quite large. Therefore, simplified models are not recommended for applications involving particularly valuable resources, such as management of rare species, or for determining mitigation needs. The use of low-resolution models to compare different sites may also be unreliable unless differences are great.

76. To evaluate the performance of simplified HSI models, their output was compared with that of the original models. This approach, however, is not equivalent to a test of a model's accuracy in predicting the quality of habitat for a species. A model can be tested by comparing its output with a standard that is thought to reflect habitat quality in the area where it is to be used. Potential standards of comparison include long-term population sizes, measurements of habitat use by individual animals, and reproductive rates or other indicators of animal well-being (Schamberger and O'Neil 1986). If the original model has been tested and found to be accurate, further testing of a simplified version may be unnecessary. However, discrete versions of untested originals should be tested before they are used to guide important land-use decisions.

Develop remote-sensing models

77. Remote-sensing models use information readily obtainable from aerial photographs or satellite imagery to estimate habitat suitability with little or no effort put into onsite sampling. Different levels of resolution are possible depending upon the photographic scale. Scales in the range of 1:32,000 to 1:92,000 may be sufficient to measure interspersion of different cover types, whereas 1:9,600 or larger may be needed to measure tree height, crown diameter, and other structural details of vegetative stands (Aldrich 1979, Mayer 1984). Other habitat features that are important to wildlife (e.g., forest understory characteristics) may be invisible to airborne sensors. Therefore, remote-sensing models are usually less accurate than those based on field sampling, but they can be particularly valuable for rapid assessments of very large areas.

78. A number of remote-sensing models are currently available for use with HEP. The HSI model for the greater prairie-chicken (Prose 1985)

incorporates different levels of resolution depending on the needs of the user and the availability of data. One level provides a low-resolution approach based on the interspersion and juxtaposition of cover types, which can be determined from aerial photographs. All variables in the northern pintail model for breeding habitat (Suchy and Anderson 1987) can be determined from maps and photographs. Lyon (1983) developed and tested a model for American kestrels in Oregon that uses spatial characteristics of cover types. A spotted owl model (Laymon, Salwasser, and Barrett 1985) incorporates three variables taken from aerial photos. Other habitat models that can be used with HEP have been developed for elk (Pettinger, Farmer, and Schamberger 1978, Kramer 1983), moose (Ross and Aronoff 1984), black-tailed prairie dogs (Rekas 1978), and turkey (Donovan, Rabe, and Olson 1987).

79. Payne and Long (1986) developed two versions of a remote-sensing model for white-tailed deer by converting a preexisting field-oriented HSI model. The first modified model was created by dropping certain variables that could not be measured remotely and by converting other variables to forms that were more amenable to measurement from large-scale aerial photographs. For example, where the original model had incorporated the basal area of oaks greater than 10-in. dbh, the modified model used the percent canopy closure of oaks greater than 200 sq ft in canopy area. This version of the model was easier to apply than the original but still required considerable effort in photointerpretation, making it difficult to use in very large study areas.

80. A second remote-sensing model for white-tailed deer (Payne and Long 1986) was based on the distribution of cover types in the study area along with minimal information about the composition of certain types. Furthermore, variables were expressed in discrete form, reducing the level of effort required to estimate them. Thus, the capability of forest cover types to provide food (i.e., acorns) for deer was evaluated by their degree of maturity (two classes), canopy closure (four classes), deciduous nature (three classes), and dominance of oaks (three classes). Each combination of habitat characteristics was assigned a standard SI value. This form of the model is more useful in large study areas because it involves less photointerpretation and permits the use of relatively small-scale photography.

Assign standard ratings based on cover type and condition

81. Habitat assessments and inventories over very large tracts of land can be simplified by assuming that all patches of vegetation in similar condition have the same suitability for one or more wildlife species. This approach is used by the Forest Service (e.g., Verner and Boss 1980) to guide management decisions in the National Forests. Verner and Boss (1980) present habitat suitability ratings for forest stands in California based on habitat type (e.g., chaparral, blue oak [*Quercus douglasii*] savannah), successional stage, and canopy closure. Stands are rated as (a) optimal, (b) suitable, or (c) marginal for breeding, feeding, and resting by each species using them.

82. This approach takes advantage of information collected during periodic forest inventories and is suited to the stand-oriented management activities of the Forest Service. As a habitat evaluation method, it is useful over large areas where variation in actual habitat value can be reduced to an average for each stand type. In any single stand, however, habitat suitability may differ markedly from the average for that type because of variations in habitat variables. Therefore, the method is not suited to small study areas unless additional details of habitat condition are considered or unless a very low-resolution result is acceptable. The approach used by Payne and Long (1986) can be used to add important details to the classification system and increase the reliability of habitat suitability ratings (see paragraph 80).

Consider other ways to estimate habitat suitability

83. As an alternative to HSI models, other kinds of information, if available, can be used to estimate habitat quality; these include long-term population levels for the species of interest, estimates of productivity or recruitment, measures of habitat use, and habitat-quality ratings by species experts. To be used with HEP, a measure of quality should be expressed on a ratio scale, be related to the long-term carrying capacity of the habitat, and should be converted to an index between 0 and 1.0 by dividing the measure by the largest value encountered in the study area or region (USFWS 1980).

84. Population data may take the form of density or biomass estimates (e.g., songbird censuses, winter deer counts, fish standing crop) or indices

to abundance (e.g., call counts, hunter harvests, creel surveys), and may be available for a project area from the appropriate State agency or a nearby university. Population data should span several years to dampen the effect of annual fluctuations. The use of population data to indicate habitat quality assumes that the population is not limited by predators, disease, human exploitation, weather, or any other factor not related to habitat (Van Horne 1983). The output of other population-oriented habitat evaluation methods (e.g., the Benthic Resources Assessment Technique (Lunz and Kendall 1982)) can also be used as input to HEP.

85. Estimates of productivity, particularly for game species, may be available from State fish and wildlife agencies for particular management units, lakes, or stream reaches. However, information on productivity can be difficult to interpret; productivity may be directly related to habitat quality but is often inversely related to population density. Indices of habitat use by individual animals, such as those obtained through radiotelemetry, may also reflect habitat quality at least within the animal's home range.

86. Recognized experts on the habitat requirements of a species can also be used in place of a model to rate the quality of an area. Experts should be asked to provide a written explanation of their ratings. The use of experts has the disadvantages that different experts may give slightly different scores to the same area, ratings of a site by the same expert may not be repeatable from one time to the next, and experts may not be available when needed. Advantages can include being able to get ratings in a timely and economical manner, gaining access to unpublished information, and obtaining area-specific ratings.

Sampling

87. Sampling of habitat characteristics in the field is often the most time-consuming and expensive aspect of a habitat evaluation. Much of this paper has focused on ways to reduce the need for or complexity of sampling. The following are some additional options to reduce the field effort involved in using HEP:

a. Relax requirements for precision of estimates.

b. Tailor sampling effort to the shape of SI curves.

c. Use visual estimates of habitat variables.

d. Use systematic rather than random sampling designs.

Relax requirements for precision of estimates

88. The precision of an estimate of a habitat variable depends on the sample size used to compute the estimate. It also depends on the underlying variability of the characteristic being measured. The level of precision achieved in a habitat assessment is at the discretion of the user and can be tailored to a particular application.

89. The USFWS (1980) recommends that habitat variables be measured with 90-percent confidence that the true value is within 25 percent of the estimate (i.e., 25-percent relative precision). For low-resolution HEP studies or those not involving the formulation of mitigation plans, the precision of estimates can be reduced to permit smaller sample sizes and less effort in the field. For example, to estimate the average dbh of overstory trees in an area where the actual mean dbh is 20 in. and the standard deviation is 10 in. would require a sample size of 11 trees to achieve 90-percent confidence and 25-percent relative precision. At the 80-percent confidence level, only seven measurements are needed.

Tailor sampling effort to the shape of SI curves

90. Actually, it is the precision of the SIs, not the variables, that determines the precision of the overall HSI estimate, and the precision of an SI value depends on the slope of the suitability curve. When the curve is steep, a small amount of uncertainty in the estimate of the variable results in a large uncertainty in the SI value. For example, Figure 3 shows how measurements with different means but the same absolute precision can result in SI values with very different precisions. If field measurements of percent cover average 15 with precision ±10, the corresponding SI is 0.0 ± 0.0. For percent cover of 50 ± 10, the SI is 0.11 ± 0.04; for 85 ± 10, the SI is 0.60 ± 0.27. In region A of the curve, uncertainty in the estimate of the habitat variable has no effect on the constant SI value. In regions B and C, the same levels of absolute precision in the variable result in different levels of precision in the SI.

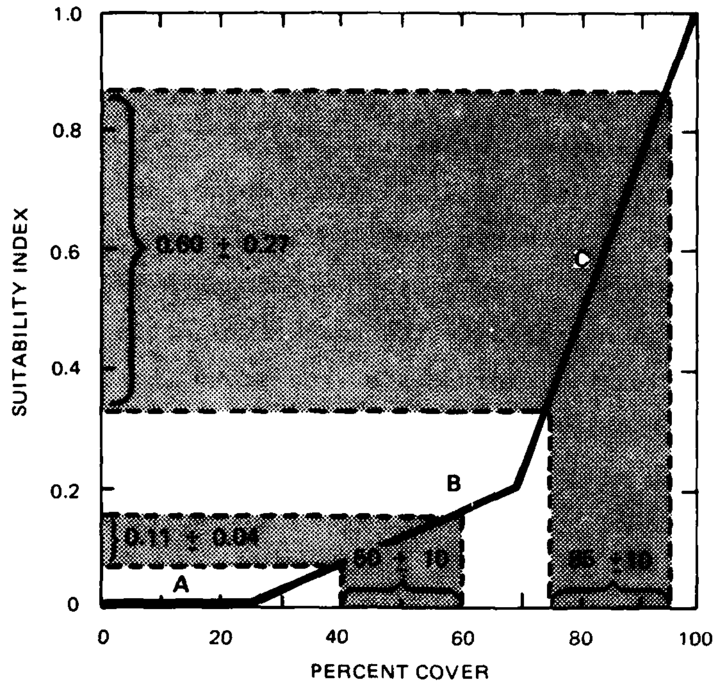

Figure 3. Effect of shape of the suitability index curve on precision of SI values

91. It is possible to reduce sample sizes, even when a high-resolution assessment is desired, by examining the suitability curves in HSI models and noting intervals within each variable where the precision of the estimates can be relaxed without affecting the precision of the SI significantly. For example, on a study site where a visual estimate of the variable falls within a part of the suitability curve where the slope is steep (e.g., region C in Figure 3), measure the variable with full recommended precision. On a site where the variable is within an interval of gentle slope (e.g., region B), reduce the required precision or confidence level. If the visual estimate of a variable clearly falls within an interval where the SI curve is flat (e.g., region A), there is no need to sample; simply record the visual estimate.

Use visual estimates of habitat variables

92. For certain applications of HEP, visual estimates of habitat variables may be adequate to meet study objectives. Other than the travel time required to inspect appropriate sites, the use of visual estimates can reduce sampling effort substantially. Limited use of visual estimates has already

been mentioned in applications involving discrete models (paragraph 72) and for variables whose SI curves are flat (paragraph 91). Complete reliance on ocular estimates may also be appropriate for low-resolution assessments or when only general trend data are needed.

93. Williamson (1976) and Williamson, Guynn, and Perkins (1978) asked five evaluators to estimate browse availability (scored on a six-point scale) for white-tailed deer on 15 sample plots within each of 14 forest stands in Mississippi. Although scores differed among evaluators at the plot level, there were no significant differences at the stand level. The evaluators' average scores were highly correlated with actual browse availability as estimated by clipping and weighing. Browse availability on 15 plots could be estimated visually in 15 to 20 min; clipping and weighing took 6.5 hr.

94. Two problems with visual estimates make them appropriate only when reliability of the HSI predictions is not a primary concern. The first, lack of precision, results in HSI values that are not repeatable by different observers or at different times by the same observer. The second problem is bias resulting from the consistent overestimation or underestimation of variables, producing HSI values that are always either too high or too low.

95. Doering and Armijo (1986) compared the use of visual estimates and field measurements of habitat variables in a HEP application involving 13 species. They found that the number of habitat units for all species combined differed by only 12 percent, and differences for all but one of the individual species ranged from 0 to 41 percent (HUs for one species differed by 296 percent). Visual estimates of habitat variables produced underestimates of HUs for 10 of the 13 species.

96. Not all variables in all cover types can be estimated with equal reliability. Mule (1982) reported that estimates of several variables made in dense or structurally complex cover types were not as precise as those made in less complex cover. In addition, visual estimates of percent cover made by 10 observers studied by Sykes, Horrill, and Mountford (1983) were more variable for fine-leaved than for broad-leaved species. For the average observer, a 90-percent confidence interval around the cover estimate was ±10 to 20 percent of the mean.

97. Extreme levels of plant cover (e.g., near zero or 100 percent) can be estimated with less error than intermediate values (Hatton, West, and Johnson 1986). Therefore, systems that classify cover into discrete

categories generally use smaller classes at the ends of the scale. For example, Daubenmire (1959) recommended cover classes of 0 to 5, 5 to 25, 25 to 50, 50 to 75, 75 to 95, and 95 to 100 percent.

98. The reliability of visual estimates for variables such as percent cover can be improved by using small quadrats and calibrating the eye against known values obtained by measurement, by using the same observers repeatedly, or by calibrating observers against each other at the start of each field session and periodically during the day (Hays, Summers, and Seitz 1981; Hamilton and Bergersen 1984). In an application involving many variables, Mulé (1982) found that precision among evaluators could be improved by clearly defining and agreeing upon the item to estimate, using simple measuring devices whenever possible (avoiding totally ocular estimates), and practicing. Moen and Severinghaus (1986) developed a simple dichotomous key for use in estimating numbers, either whole numbers or percentages, that may improve repeatability of estimates within and among individuals. An additional approach involves the use of three or more observers who inspect each site simultaneously but independently and then meet to discuss their estimates and resolve differences before proceeding to the next site.

Use systematic rather than random sampling designs

99. Sampling of habitat features should be unbiased, but that does not necessarily mean that sampling sites must be located entirely at random. Most users of HEP rely on systematic sampling designs; these can be unbiased if laid out at random with respect to the variable(s) being measured. Systematic designs often require less sampling effort because little time is wasted finding and traveling to the next sampling point.

100. Sampling for canopy closure in shrubland habitat, for example, could involve considerable waste of energy if point-intercept sampling locations were scattered at random throughout the cover type. Instead, a more efficient design might involve a sample of points located at constant intervals along a transect whose starting point was randomly selected. This systematic sample should be unbiased as long as the study site is fairly homogeneous. For sites whose characteristics change gradually along a gradient of moisture or soil conditions, transects should be established parallel to the gradient.

Data Handling and Analysis

101. A significant part of the time spent on a HEP study consists of routine office chores such as compiling and transcribing field data, doing preliminary calculations of habitat variables, computing SIs and HUs, and working through the HEP accounting framework. The following options can increase efficiency and reduce errors involved in these tasks:

a. Use a portable computer to record data in the field.

b. Use available HSI and HEP software.

c. Develop personalized computer applications.

Use a portable computer *to record data in the field*

102. Computers are now so small that useful models are no bigger than a hand calculator. However, computers differ from calculators in at least two important ways. First, they are programmable, so that users can adapt the machines to their specific needs. Second, they contain internal memory that can store data in either raw or summarized form. Later, the stored information can be transferred directly into a larger computer for printing or additional processing. Portable computers for data collection can increase the efficiency of a HEP study by eliminating the need for data forms, helping to flag incorrect data values, reducing transcription errors, and performing preliminary calculations.

103. Efficient use of a portable computer may require knowledge of a programming language (e.g., BASIC). General-purpose computers, such as the Radio Shack TRS-80 Model 100 Portable Computer or the Sharp PC-1500 Pocket Computer, accept BASIC programs that can instruct the computer to ask for certain data (e.g., DBH, TREE #1?), calculate summary statistics (e.g., MEAN DBH = 24.5), and store the results. When the storage area is full, the user electronically transfers the data to a desktop microcomputer. General-purpose computers are not designed to withstand extremes of temperature and are not sealed against moisture or dirt. However, a complete system can be purchased

for less than $500. An adequate measure of protection can be gained by enclosing it in a transparent plastic bag during use.*

104. A second class of portable computers consists of specialized devices designed for rugged field use, often in forestry. These "portable data collectors" (Cooney 1985) offer light weight (1 to 4 lb), durability, and programmability. They have rechargeable power supplies, 8- to 256-kilobyte memories, and small liquid-crystal or light-emitting diode displays. Some models accept programs transferred from a host computer and data directly from sensors (e.g., thermistors) in the field. Approximate base prices range from $700 to $4,000.

Use available HSI and HEP software

105. At one time, a HEP analysis involved laborious and time-consuming hand calculation of HSI values and a number of HUs for each evaluation species, annualized impacts for various alternative project designs, and compensation requirements. With the development of improved versions of HSI and HEP software by the USFWS, the most complex analysis can now be done quickly and efficiently. A summary of available software is found in O'Neil (1985), sections 9a and 9b (updated February 1988).

106. HSI software allows the user to construct HSI models or to draw from an extensive library of models provided by the USFWS. Model construction and modification require little or no programming knowledge. The software prompts for values for each habitat variable, which can be entered from the keyboard or from a file. HSI values are then calculated and displayed. The user also has the option of displaying intermediate values in the HSI calculation (e.g., individual SIs and life requisite SIs).

107. The basic inputs required by the HEP software are HSI values and acres of available habitat for each evaluation species. Information is entered for current conditions and for each target year under various project alternatives and management plans. If desired, the program also accepts relative value indices (RVIs) directly or calculates them based on pair-wise comparisons of the evaluation elements. The printed output consists of standard forms B, C, D, E, F, G1, G2, and H, which present the number of HUs for

* Personal Communication, March 1986, S. D. Kovach, Fish and Wildlife Specialist, Naval Facilities Engineering Command, San Bruno, CA.

each species, the AAHUs, RVIs, net change in AAHUs resulting from each project alternative, and the area needed to compensate for habitat losses.

Develop personalized computer applications

108. For small projects or those with limited objectives, available specialized software can be too complex and may require unnecessarily detailed information. The HEP software, for instance, requires at least 3 target years, which may not be appropriate for a limited study. One alternative is to adapt general-purpose software to the computing requirements of small projects.

109. Spreadsheets (e.g., VisiCalc, Lotus 1-2-3, Quatro) are software packages that can be adapted to a variety of purposes. They create in the computer a two-dimensional array of columns and rows, similar to a ledger or a tablet of cross-ruled paper. Columns and rows can be given headings, such as species names or cover types. Individual cells in the table might contain data entered by the user, such as field data, HSI values, or acreages. Values in other cells can be calculated by the computer based on previously entered data and formulas provided by the user; these might include calculations of HUs. An important advantage of computerized spreadsheets over the pencil-and-paper alternative is that all the values in a table can be instantly recalculated after any one value is changed by the user. Therefore, spreadsheets are particularly useful for visualizing changes in the outcome of a study resulting from changes in the inputs. Another advantage is the production of neat and readable printed displays that can be appended to a project report.

110. The time devoted to a habitat analysis can be reduced further by taking advantage of the speed, accuracy, and information-storage capabilities of microcomputers in all aspects of routine office operations. For example, bibliographic software can help organize and retrieve references to pertinent literature; these can be incorporated directly into documents produced by a word-processing program. A data base manager might be used to develop a guild classification for local wildlife species that could be accessed rapidly for a particular application. Statistical software can be used to determine the precision of estimates, calculate sample sizes, or test HSI models. The potential for increased efficiency is limited only by the imagination of the user.

REFERENCES

Adamus, P. R., Clairain, E. J., Jr., Smith, R. D., and Young, R. E. 1987. "Wetland Evaluation Technique (WET); Vol II," Operational Draft Technical Report, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Aldrich, R. C. 1979. "Remote Sensing of Wildland Resources: A State-of-the-Art Review," General Technical Report RM-71, Rocky Mountain Forest and Range Experiment Station, US Forest Service, Fort Collins, CO.

Alexander, R. R. 1985. "Major Habitat Types, Community Types, and Plant Communities in the Rocky Mountains," General Technical Report RM-123, Rocky Mountain Forest and Range Experiment Station, US Forest Service, Fort Collins, CO.

Allen, A. W. 1983. "Habitat Suitability Index Models: Southern Red-Backed Vole (Western United States)," Office of Biological Services 82/10.42, US Fish and Wildlife Service, Washington, DC.

Anderson, J. R., Hardy, E. E., Roach, J. T., and Witmer, R. E. 1976. "A Land Use and Land Cover Classification System for Use with Remote Sensor Data," Professional Paper 964, US Geological Survey, Washington, DC.

Avery, T. E. 1977. Interpretation of Aerial Photographs, Burgess, Minneapolis, MN.

__________. 1978. "Forester's Guide to Aerial Photo Interpretation," Agriculture Handbook 308, US Forest Service, Washington, DC.

Balda, R. P. 1975. "Vegetation Structure and Breeding Bird Diversity," Proceedings of the Symposium on Management of Forest and Range Habitats for Nongame Birds, General Technical Report WO-1, US Forest Service, Washington, DC, pp 59-80.

Best, R. G. 1982. "Handbook of Remote Sensing in Fish and Wildlife Management," SDSU-RSI-82-05, Remote Sensing Institute, South Dakota State University, Brookings, SD.

Cade, B. S. 1985. "Habitat Suitability Index Models: American Woodcock (Wintering)," Biological Report 82(10.105), US Fish and Wildlife Service, Washington, DC.

Cooney, T. M. 1985. "Portable Data Collectors, and How They're Becoming Useful," Journal of Forestry, Vol 83, No. 1, pp 18-23.

Daubenmire, R. 1959. "A Canopy-Coverage Method of Vegetation Analysis," Northwest Science, Vol 33, pp 43-64.

DeGraaf, R. M., and Rudis, D. D. 1986. "New England Wildlife: Habitat, Natural History, and Distribution," General Technical Report NE-108, Northeastern Forest Experiment Station, US Forest Service, Broomall, PA.

Doering, J. P., III, and Armijo, M. B. 1986. "Habitat Evaluation Procedures as a Method for Assessing Timber-Sale Impacts," Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates, J. Verner, M. L. Morrison, and C. J. Ralph, eds., University of Wisconsin Press, Madison, WI, pp 407-410.

Donovan, M. L., Rabe, D. L., and Olson, C. E., Jr. 1987. "Use of Geographic Information Systems to Develop Habitat Suitability Models," Wildlife Society Bulletin, Vol 15, pp 574-579.

Eyre, F. H., ed. 1980. Forest Cover Types of the United States and Canada, Society of American Foresters, Washington, DC.

Frye, R. G. 1984. "Wildlife Habitat Appraisal Procedure," Texas Parks and Wildlife Department, Austin, TX.

Garcia, J., Pratt, J., Ahlborn, G., Orloff, S., Richter, K., Dragavon, J., and Eby, J. 1984. "A Method for Assessing the Value of Stream Corridors to Fish and Wildlife Resources, Volumes I and II," Biosystems Analysis, Sausalito, CA.

Graber, J. W., and Graber, R. R. 1976. "Environmental Evaluations Using Birds and Their Habitats," Biological Note 97, Illinois Natural History Survey, Champaign, IL.

Hamilton, K., and Bergersen, E. P. 1984. "Methods To Estimate Aquatic Habitat Variables," Cooperative Fishery Unit, Colorado State University, Fort Collins, CO.

Hatton, T. J., West, N. E., and Johnson, P. S. 1986. "Relationships of the Error Associated with Ocular Estimation and Actual Total Cover," Journal of Range Management, Vol 39, No. 1, pp 91-92.

Hays, R. L., Summers, C., and Seitz, W. 1981. "Estimating Wildlife Habitat Variables," Office of Biological Services 81/47, US Fish and Wildlife Service, Washington, DC.

Hench, J. E., Flyger, V., Gibbs, R., and Van Ness, K. 1985. "Predicting the Effects of Land-Use Changes on Wildlife," Transactions of the North American Wildlife and Natural Resources Conference, Vol 50, pp 345-351.

James, F. C. and Wamer, N. O. 1982. "Relationships Between Temperate Forest Bird Communities and Vegetation Structure," Ecology, Vol 63, No. 1, pp 159-171.

Kramer, S. J. S. 1983. "A Technique To Identify Potential Elk Habitat in the White Mountains of Arizona," M.S. thesis, University of Arizona, Tucson, AZ.

Laymon, S. A., Salwasser, H., and Barrett, R. H. 1985. "Habitat Suitability Index Models: Spotted Owl," Biological Report 82(10.113), US Fish and Wildlife Service, Washington, DC.

Lunz, J. D., and Kendall, D. R. 1982. "Benthic Resources Assessment Technique, a Method for Quantifying the Effects of Benthic Community Changes on Fish Resources," Proceedings of the Oceans '82 Conference, pp 1021-1027.

Lyon, J. G. 1983. "Landsat-Derived Land-Cover Classifications for Locating Potential Kestrel Nesting Habitat," Photogrammetric Engineering and Remote Sensing, Vol 49, No. 2, pp 245-250.

Mayer, K. E. 1984. "A Review of Selected Remote Sensing and Computer Technologies Applied to Wildlife Habitat Inventories," California Fish and Game, Vol 70, No. 2, pp 102-112.

Miller, A. C., Killgore, K. J., Jr., Payne, B. S., and Franklin, J. 1987a. "Community Habitat Suitability Index Models for Warmwater Fishes," Miscellaneous Report EL-87-14, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Miller, A. C., Payne, B. S., Naimo, T. J., and Russell-Hunter, W. D. 1987b. "Gravel Bar Mussel Communities: A Community Model," Technical Report EL-87-13, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Moen, A. N., and Severinghaus, C. W. 1986. "Estimating Numbers With a Universal Key," New York Fish and Game Journal, Vol 32, No. 1, pp 89-92.

Mulé, R. S. 1982. "An Assessment of a Wildlife Habitat Evaluation Methodology for Alaska," M.S. thesis, University of Alaska, Fairbanks.

O'Neil, L. J. 1985. "Habitat Evaluation Methods Notebook," Instruction Report EL-85-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

O'Neil, L. J., Roberts, T. H., Wakeley, J. S., and Teaford, J. W. 1988. "A Procedure To Modify Habitat Suitability Index Models," Wildlife Society Bulletin, Vol 16, pp 33-36.

Payne, B. S., and Long, K. S. 1986. "Airborne Sensor Potential for Habitat Evaluation Procedures (HEP)," Technical Report EL-86-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Pettinger, L. R., Farmer, A., and Schamberger, M. 1978. "Quantitative Wildlife Habitat Evaluation Using High-Altitude Color Infrared Aerial Photographs," Proceedings of the Pecora IV Symposium: Application of Remote Sensing Data to Wildlife Management, National Wildlife Federation, pp 335-345.

Prose, B. L. 1985. "Habitat Suitability Index Models: Greater Prairie-chicken (Multiple Levels of Resolution)," Biological Report 82(10.102), US Fish and Wildlife Service, Washington, DC.

Rekas, A. M. B. 1978. "Inventory of Wildlife Habitat: An Approach and Case Study," Proceedings of the Pecora IV Symposium: Application of Remote Sensing Data to Wildlife Management, National Wildlife Federation, pp 346-352.

Roberts, T. H., and O'Neil, L. J. 1985a. "Species Selection for Habitat Assessments," Transactions of the North American Wildlife and Natural Resources Conference, Vol 50, pp 352-362.

__________. 1985b. "Species Selection for Habitat Assessments," Miscellaneous Paper EL-85-8, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Ross, G., and Aronoff, S. 1984. "Use of Remotely Sensed Data in Environmental Planning--A Case Study of Environmental Analysis for Gas Field Facilities Development Planning," Journal of Environmental Management, Vol 19, pp 1-14.

Schamberger, M. L., and O'Neil, L. J. 1986. "Concepts and Constraints of Habitat-Model Testing," Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates, J. Verner, M. L. Morrison, and C. J. Ralph, eds., University of Wisconsin Press, Madison, WI, pp 5-10.

Schroeder, R. L. 1985. "Habitat Suitability Index Models: Eastern Wild Turkey," Biological Report 82(10.106), US Fish and Wildlife Service, Washington, DC.

__________. 1986. "Habitat Suitability Index Models: Wildlife Species Richness in Shelterbelts," Biological Report 82(10.128), US Fish and Wildlife Service, Washington, DC.

Schroeder, R. L. 1987. "Community Models for Wildlife Impact Assessment: A Review of Concepts and Approaches," Biological Report 87(2), US Fish and Wildlife Service, Washington, DC.

Short, H. L. 1984. "Habitat Suitability Index Models: The Arizona Guild and Layers of Habitat Models," Office of Biological Services 82/10.70, US Fish and Wildlife Service, Washington, DC.

Stiles, E. W. 1978. "Vertebrates of New Jersey," Rutgers University, New Brunswick, NJ.

Suchy, W. J., and Anderson, S. H. 1987. "Habitat Suitability Index Models: Northern Pintail," Biological Report 82 (10:145), US Fish and Wildlife Service, Washington, DC.

Sykes, J. M., Horrill, A. D., and Mountford, M. D. 1983. "Use of Visual Cover Assessments as Quantitative Estimators of Some British Woodland Taxa," Journal of Ecology, Vol 71, pp 437-450.

Urich, D. L., and Graham, J. P. 1984. "A Handbook for Wetland Habitat Evaluation in Missouri," Missouri Department of Conservation, Columbia, MO.

Urich, D. L., Graham, J. P., and Cook, C. C. 1983. "A Handbook for Habitat Evaluation in Missouri," Missouri Department of Conservation, Columbia, MO.

US Army Corps of Engineers. 1980. "A Habitat Evaluation System for Water Resources Planning," US Army Engineer Division, Lower Mississippi Valley, Vicksburg, MS.

US Fish and Wildlife Service. 1980. "Habitat Evaluation Procedures (HEP)," Ecological Services Manual 102, Division of Ecological Services, Washington, DC.

__________. 1981. "Standards for the Development of Habitat Suitability Index Models," Ecological Services Manual 103, Division of Ecological Services, Washington, DC.

Van Horne, B. 1983. "Density as a Misleading Indicator of Habitat Quality," Journal of Wildlife Management, Vol 47, pp 893-901.

Verner, J., and Boss, A. S., tech. coords. 1980. "California Wildlife and Their Habitats: Western Sierra Nevada," General Technical Report PSW-37, Pacific Southwest Forest and Range Experiment Station, US Forest Service, Berkeley, CA.

Waldon, J., ed. 1987. "Multi-State Fish and Wildlife Information Systems Newsletter," Department of Fisheries and Wildlife Science, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Williamson, J. F., Jr. 1976. "The Feasibility of a Subjective Habitat Evaluation Technique," M.S. thesis, Mississippi State University, Mississippi State, MS.

Williamson, J. F., Jr., Guynn, D. C., Jr., and Perkins, C. J. 1978. "The Feasibility of a Subjective Habitat Evaluation Technique," Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies, Vol 32, pp 154-159.

Willson, M. F. 1974. "Avian Community Organization and Habitat Structure," Ecology, Vol 55, No. 5, pp 1017-1029.

APPENDIX A: COMMON AND SCIENTIFIC NAMES OF ANIMALS MENTIONED IN TEXT

Common Name	Scientific Name
Alewife	*Alosa pseudoharengus*
American alligator	*Alligator mississippiensis*
American black duck	*Anas rubripes*
American kestrel	*Falco sparverius*
American oyster	*Crassostrea virginica*
American shad	*Alosa sapidissima*
American woodcock	*Scolopax minor*
Arctic grayling	*Thymallus arcticus*
Atlantic croaker	*Micropogon undulatus*
Baird's sparrow	*Ammodramus bairdii*
Bald eagle	*Haliaeetus leucocephalus*
Barred owl	*Strix varia*
Beaver	*Castor canadensis*
Belted kingfisher	*Ceryle alcyon*
Bigmouth buffalo	*Ictiobus cyprinellus*
Black bear	*Ursus americanus*
Black brant	*Branta bernicla*
Black bullhead	*Ictalurus melas*
Black crappie	*Pomoxis nigromaculatus*
Black-capped chickadee	*Parus atricapillus*
Black-shouldered kite	*Elanus caeruleus*
Black-tailed prairie dog	*Cynomys ludovicianus*
Blacknose dace	*Rhinichthys atratulus*
Blue grouse	*Dendragapus obscurus*
Blue-winged teal	*Anas discors*
Blueback herring	*Alosa aestivalis*
Bluegill	*Lepomis macrochirus*
Bobcat	*Felis rufus*
Brewer's sparrow	*Spizella breweri*
Brook trout	*Salvelinus fontinalis*
Brown shrimp	*Penaeus aztecus*
Brown thrasher	*Toxostoma rufum*
Brown trout	*Salmo trutta*
Bullfrog	*Rana catesbeiana*
Cactus wren	*Campylorhynchus brunneicapillus*
Canvasback	*Aythya valisineria*
Channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscha*
Chum salmon	*Oncorhynchus keta*
Clapper rail	*Rallus longirostris*
Coho salmon	*Oncorhynchus kisutch*
Common carp	*Cyprinus carpio*
Common shiner	*Notropis cornutus*
Creek chub	*Semotilus atromaculatus*
Cutthroat trout	*Salmo clarki*
Downy woodpecker	*Picoides pubescens*

(Continued)

(Sheet 1 of 4)

Common Name	Scientific Name
Eastern brown pelican	*Pelecanus occidentalis*
Eastern cottontail	*Sylvilagus floridanus*
Eastern meadowlark	*Sturnella magna*
Eastern wild turkey	*Meleagris gallopavo sylvestris*
Elk	*Cervus canadensis*
English sole	*Parophrys vetulus*
Fallfish	*Semotilus corporalis*
Ferruginous hawk	*Buteo regalis*
Field sparrow	*Spizella pusilla*
Fisher	*Martes pennanti*
Flathead catfish	*Pylodictis olivaris*
Forster's tern	*Sterna forsteri*
Fox squirrel	*Sciurus niger*
Gadwall	*Anas strepera*
Gizzard shad	*Dorosoma cepedianum*
Gray partridge	*Perdix perdix*
Gray squirrel	*Sciurus carolinensis*
Great blue heron	*Ardea herodias*
Great egret	*Casmerodius albus*
Greater prairie chicken	*Tympanicus cupido*
Greater sandhill crane	*Grus canadensis tabida*
Greater white-fronted goose	*Anser albifrons*
Green sunfish	*Lepomis cyanellus*
Gulf flounder	*Paralichthys albigutta*
Gulf menhaden	*Brevoortia patronus*
Hairy woodpecker	*Picoides villosus*
Hard clam	*Mercenaria mercenaria*
Inland silverside	*Menidia beryllina*
Lake trout	*Salvelinus namaycush*
Largemouth bass	*Micropterus salmoides*
Lark bunting	*Calamospiza melanocorys*
Laughing gull	*Larus atricilla*
Least tern	*Sterna antillarum*
Lesser scaup	*Aythya affinis*
Lesser snow goose	*Chen caerulescens*
Lewis' woodpecker	*Melanerpes lewis*
Littleneck clam	*Protothaca staminea*
Longnose dace	*Rhinichthys cataractae*
Longnose sucker	*Catostomus catostomus*
Mallard	*Anas platyrhynchos*
Marsh wren	*Cistothorus palustris*
Marten	*Martes americana*
Mink	*Mustela vison*
Moose	*Alces alces*
Mottled duck	*Anas fulvigula*
Muskellunge	*Esox masquinongy*
Muskrat	*Ondatra zibethicus*

(Continued)

(Sheet 2 of 4)

Common Name	Scientific Name
Northern bobwhite	*Colinus virginianus*
Northern pike	*Esox lucius*
Northern pintail	*Anas acuta*
Paddlefish	*Polyodon spathula*
Pileated woodpecker	*Dryocopus pileatus*
Pine warbler	*Dendroica pinus*
Pink salmon	*Oncorhynchus gorbuscha*
Pink shrimp	*Penaeus duorarum*
Plains sharp-tailed grouse	*Tympanuchus phasianellus jamesi*
Pronghorn	*Antilocapra americana*
Rainbow trout	*Salmo gairdneri*
Red-cockaded woodpecker	*Picoides borealis*
Red drum	*Sciaenops ocellata*
Red-spotted newt	*Notophthalmus viridescens*
Red-winged blackbird	*Agelaius phoeniceus*
Redbreast sunfish	*Lepomis auritus*
Redear sunfish	*Lepomis microlophus*
Redhead	*Aythya americana*
Roseate spoonbill	*Ajaia ajaja*
Ruffed grouse	*Bonasa umbellus*
Shortnose sturgeon	*Acipenser brevirostrum*
Slider turtle	*Pseudemys scripta*
Slough darter	*Etheostoma gracile*
Smallmouth bass	*Micropterus dolomieui*
Smallmouth buffalo	*Ictiobus bubalus*
Snapping turtle	*Chelydra serpentina*
Snowshoe hare	*Lepus americanus*
Southern flounder	*Paralichthys lethostigma*
Southern kingfish	*Menticirrhus americanus*
Southern red-backed vole	*Clethrionomys gapperi*
Spot	*Leiostomus xanthurus*
Spotted bass	*Micropterus punctulatus*
Spotted owl	*Strix occidentalis*
Spotted seatrout	*Cynoscion nebulosus*
Striped bass	*Morone saxatilis*
Swamp rabbit	*Sylvilgagus aquaticus*
Veery	*Catharus fuscenscens*
Walleye	*Stizostedion vitreum*
Warmouth	*Lepomis gulosus*
Western grebe	*Aechmophorus occidentalis*
White bass	*Morone chrysops*
White crappie	*Pomoxis annularis*
White ibis	*Eudocimus albus*
White shrimp	*Penaeus setiferus*
White sucker	*Catostomus commersoni*

(Continued)

(Sheet 3 of 4)

Common Name	Scientific Name
White-tailed deer	*Odocoileus virginianus*
Williamson's sapsucker	*Sphyrapicus thyroideus*
Wood duck	*Aix sponsa*
Yellow perch	*Perca flavescens*
Yellow warbler	*Dendroica petechia*
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*

(Sheet 4 of 4)